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published in
Ergonomics
2004

DOI (link to publisher)
10.1080/00140130310001617967

document version
Publisher's PDF, also known as Version of record

ERGONOMICS, 5 FEBRUARY, 2004, VOL. 47, NO. 2, 202–217

Effects of precision demands and mental pressure on muscle activation and hand forces in computer mouse tasks

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Keywords: Computer work; Upper extremity musculoskeletal disorders; EMG.

The objective of the present study was to gain insight into the effects of precision demands and mental pressure on the load of the upper extremity. Two computer mouse tasks were used: an aiming and a tracking task. Upper extremity loading was operationalized as the myo-electric activity of the wrist flexor and extensor and of the trapezius descendens muscles and the applied grip- and click-forces on the computer mouse. Performance measures, reflecting the accuracy in both tasks and the clicking rate in the aiming task, indicated that the levels of the independent variables resulted in distinguishable levels of accuracy and work pace. Precision demands had a small effect on upper extremity loading with a significant increase in the EMG-amplitudes (21%) of the wrist flexors during the aiming tasks. Precision had large effects on performance. Mental pressure had substantial effects on EMG-amplitudes with an increase of 22% in the trapezius when tracking and increases of 41% in the trapezius and 45% and 140% in the wrist extensors and flexors, respectively, when aiming. During aiming, grip- and click-forces increased by 51% and 40% respectively. Mental pressure had small effects on accuracy but large effects on tempo during aiming. Precision demands and mental pressure in aiming and tracking tasks with a computer mouse were found to coincide with increased muscle activity in some upper extremity muscles and increased force exertion on the computer mouse. Mental pressure caused significant effects on these parameters more often than precision demands. Precision and mental pressure were found to have effects on performance, with precision effects being significant for all performance measures studied and mental pressure effects for some of them. The results of this study suggest that precision demands and mental pressure increase upper extremity load, with mental pressure effects being larger than precision effects. The possible role of precision demands as an indirect mental stressor in working conditions is discussed.

1. Introduction

Epidemiological studies and reviews clearly show that work related upper extremity musculoskeletal disorders (UEMSDs) have become a major problem over the last

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Ergonomics ISSN 0014-0139 print/ISSN 1366-5847 online © 2004 Taylor & Francis Ltd
http://www.tandf.co.uk/journals
DOI: 10.1080/00140130310001617967

decades, with high and apparently increasing incidence and prevalence rates (Bernard 1997, Buckle and Devereux 1999, Sluiter *et al.* 2000). Although the pathophysiology of these disorders is still largely unknown, several risk factors such as force, precision and task stress have been identified (Ekberg *et al.* 1994, Milerad and Ericson 1994, Ariëns *et al.* 2001, Buckle and Devereux 2002).

There are indications that UEMSDs are related to computer work (Fogleman and Brogmus 1995, Karlqvist *et al.* 1996, Punnett and Bergqvist 1997, Jensen *et al.* 2002). In a few studies mouse use is indicated as a risk factor in computer work (Karlqvist *et al.* 1996, Jensen *et al.* 1998, 2002).

During computer work, static contractions of the shoulder and neck muscles occur to maintain the position of the arm in the gravitational field (Visser *et al.* 2000). Although the muscle activity can be reduced by adding a horizontal support to the forearm, it cannot be entirely obviated (Visser *et al.* 2000). Static contractions of proximal musculature, often combined with dynamic contractions of the distal musculature, are known to form a high risk with respect to UEMSDs (Bernard 1997, Sluiter *et al.* 2000). Physiological lines of evidence suggest that sustained contractions of arm and neck muscles even at relatively low intensities may explain this association (Gissel 2000, Hägg 2000, Sjøgaard *et al.* 2000).

On the basis of theoretical considerations it has been suggested that the duration and intensity of sustained muscle contractions are influenced by the precision demands of a task. To obtain sufficient positional accuracy of the end-effectors (hands, fingers, or tools) the arm and shoulder girdle need to be stabilised by means of muscular activity. Stability in the proximal upper extremity joints can be achieved by co-contraction of muscles spanning these joints (Akazawa *et al.* 1983). In addition, in the distal joints increased precision demands may coincide with increased cocontraction. The neuro-motor noise theory suggests that, in high precision movements, the noise effects in neuro-motor control are counteracted by means of increased cocontraction. The stiffness provided by cocontraction is expected to filter out noise effects (Galen *et al.* 1996, Gemmert and Galen 1997, Gemmert and Galen 1998, Seidler-Dobrin *et al.* 1998, Galen *et al.* 2002). At low intensities the unfavourable signal to noise ratio of neural control (Galen and de Jong 1995) may increase the necessity of cocontractions. The level of cocontraction will be even higher under stressful tasks conditions because of the increased neural noise under these conditions (Galen *et al.* 2002).

Computer work often comprises high precision and concentration demands and high time pressure. In epidemiological studies it is extremely difficult to disentangle the effects of precision demands and mental pressure due to concentration and time pressure. Earlier experimental studies have mostly involved one exposure in isolation while keeping other factors constant.

The aim of the present study was to gain insight into the effects on the load of the upper extremity of precision demands and mental pressure (to perform accurately and to perform at highest speed). Several combinations of precision demands and mental pressure were imposed in two computer mouse tasks: an aiming and a tracking task. Tracking and aiming tasks were used to disentangle the different underlying aspects of precision and mental pressure (such as accuracy and speed) while still allowing the results to be generalized to computer work. Aiming is very common in computer work but has a disadvantage as an experimental task due to the interaction between speed and accuracy (Laursen *et al.* 1998). The tracking task is less common in computer work but has a distinct advantage in that movement velocity can be controlled.

The upper extremity load was operationalized as (1) the myo-electric activity of the forearm and neck-shoulder muscles and (2) the grip- and click-forces applied on the computer mouse.

For the mouse tracking and aiming tasks, it was hypothesized that a higher precision demand or a higher level of mental pressure would contribute to higher grip- and click-forces and higher EMG levels.

The effects of precision demands and mental pressure on task performance were studied, to verify that the experimental conditions were chosen such that the subjects' effort was affected as intended.

2. Methods

2.1. *Subjects*

Ten healthy right-handed subjects (four males, six females) participated in the study. Prior to the experiment, the subjects filled out an informed consent form. They had experience in computer work, but were not professional computer workers. Their ages varied between 23 and 58 years.

2.2. *Procedure*

The subjects performed two computer mouse tasks: a tracking task and an aiming task. Each task was performed at two levels of precision and two levels of mental pressure.

In the tracking task, subjects made the cursor follow a dot moving anti-clockwise in a circle at a fixed speed on the computer screen. The level of precision was set by the diameter of the dot, which was respectively 50 and 15 pixels for low and high precision. Mental pressure was increased in the high pressure condition by a verbal instruction to perform as well as possible in combination with the provision of performance feedback. This feedback was presented on the screen as a bar, which decreased in height when the cursor was not on the dot, with the magnitude of the decrease depending on the distance between cursor and dot. The task comprised completing eight circles with a duration of 15 s each, resulting in a total task duration of 120 s.

In the aiming task, subjects were asked to click on a dot, which appeared at random locations on the computer screen. The level of precision was again defined by the diameter of the dot (50 and 15 pixels for low and high precision, respectively). In the low mental pressure condition, 60 dots were presented on the screen with an interval of two seconds between the dots, resulting in a total task duration of 120 s. In the high mental pressure condition the subjects had to make 60 correct clicks as quickly as possible. A penalty of two extra dots was given for each miss (clicking with the cursor outside the border of the dot).

To exclude order effects, the precision and mental pressure conditions were presented to the subjects in an order as varied as possible.

The workplace in which the tasks were performed was a common computer workplace with a keyboard, a standard computer mouse and a 17 inch monitor. Prior to the experiments the workplace was adjusted to the anthropometry of the individual subject according to common ergonomic guidelines. Subjects were seated on a wheeled chair, with height adjustable arm rests. The table was adjusted to elbow height.

2.3. *Measurements and data analysis*

Muscular activity was measured by means of electromyography (EMG). EMG signals were recorded from three muscles at the subject's dominant side:

- a neck-shoulder muscle (musculus trapezius pars descendens), abbreviated as 'trapezius' in the results;
- and two forearm muscles (musculus extensor digitorum, musculus flexor digitorum superficiales), abbreviated as 'extensor' and 'flexor' respectively.

Prior to the experimental trials, maximal voluntary contractions (MVCs) of each muscle were obtained using manual resistance as described by Kendall *et al.* (1983). MVCs with a duration of three seconds were performed three times with at least 30 s rest between two contractions. The trial with the highest 1-second average of the EMG was used to define the subject's MVC.

Standard procedures were followed for the use of surface EMG (Hermens *et al.* 1999). Bipolar Ag/AgCl surface electrodes (Medicotest, Rugmarken, Denmark) were used with an inter-electrode distance of 20 mm. Signals were amplified 20 times (Porti-17^{TM}, TMS, Enschede, The Netherlands, input impedance $> 10^{12}\Omega$, CMRR > 90 dB), band-pass filtered (10 – 300 Hz) and A – D converted (22 bits) at 1000 Hz. EMG data were digitally rectified, filtered (4th order Butterworth lowpass 5 Hz) and normalized to the maximal voluntary contractions (MVCs). Data reduction was obtained by extracting the median level (P50) from the Amplitude Probability Distribution (Jonsson 1978).

The mouse used in the experiments is shown in figure 1. The mouse was equipped with two force transducers, a click-force and a grip-force transducer. The click-force transducer (type FSL05N2C, Honeywell, Morris Township, NJ, USA) was placed internally in the mouse under the left mouse button. This transducer measures the contact force of the index finger on the left mouse button. The mouse further includes a force transducer (Force Sensing Resistor model 402, Interlink Electronics, Eternach, Luxembourg) on the left side to measure the grip- force of the user's thumb on the device. This transducer was placed at the outside and is visible as a black circle in figure 1. The subjects were instructed to place their thumb on the transducer whenever they used their thumb in manipulating the mouse. The transducer was very thin but of a different surface texture compared to the mouse and so gave tactile feedback about where to position the thumb. The sampling frequency of the click- and grip-forces was 20 Hz. Calculations were made on the force data for the periods that force was applied to the transducers; zero values were eliminated from the recordings. The mean grip-force was calculated for each task, and the mean click-force was calculated for the aiming task.

The position (XY-coordinates) of the centre of the target dot and the position of the cursor were recorded. During the tracking tasks a sampling frequency of 50 Hz was used, and during the aiming tasks the positions were recorded at each mouse click.

Two performance measures were calculated for each tracking task:

- Distance—The mean distance (pixels) between the cursor and the middle of the target dot.
- % Missing—The percentage of the time the cursor was not positioned on the target dot.

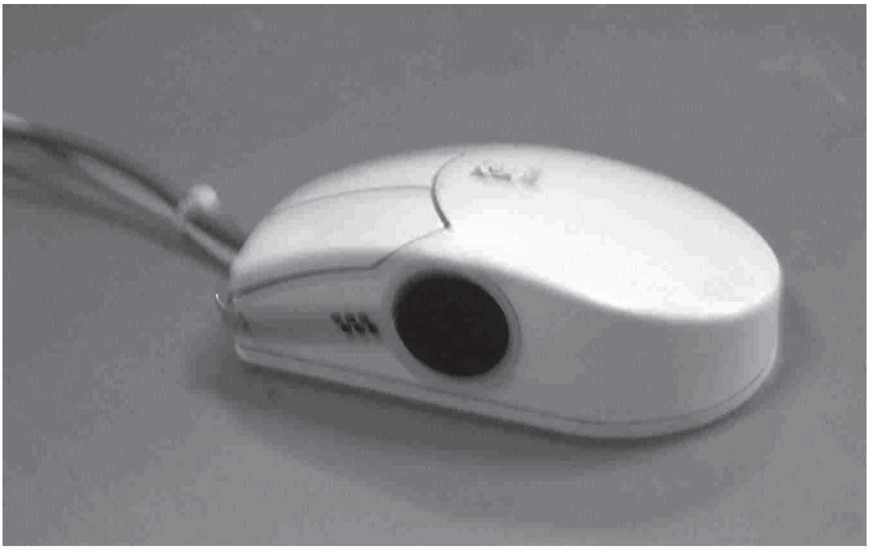


Figure 1. The instrumented mouse.

Three performance measures were calculated for each aiming task:

- Distance—The mean distance (pixels) between the cursor and the middle of the target dot at the moment of clicking.
- Missed—The number of missed dots until 60 correct clicks were made.
- Time/click—The time per click, calculated over the first 60 clicks.

2.4. *Statistical analysis*

The effects of mental pressure and precision demands on the mouse forces, EMG amplitudes and performance measures during the mouse aiming and tracking tasks were evaluated using analysis of variance (ANOVA) for repeated measures. Prior to the application of the ANOVA, the performance measures were transformed, using a log-transformation. A paired *t*-test was used for *post hoc* testing. A *p*-value less than 0.05 was considered to be statistically significant.

3. Results

3.1. *Performance measures*

The performance results for the tracking task are presented in figure 2 and the corresponding statistics in table 1. Precision demands and mental pressure both had a significant effect on the mean distance between the cursor and the middle of the target dot (see figure 2a). High precision demands and high mental pressure led to smaller distances between cursor and the middle of the target dot.

Precision demands and mental pressure also had a significant effect on the percentage of the time the cursor was not positioned on the target dot (see figure 2b). The high precision level led to high percentages of the time the cursor was not on the dot. The effect of mental pressure was much smaller and opposite in direction; under high pressure the cursor was on the dot a higher percentage of time.

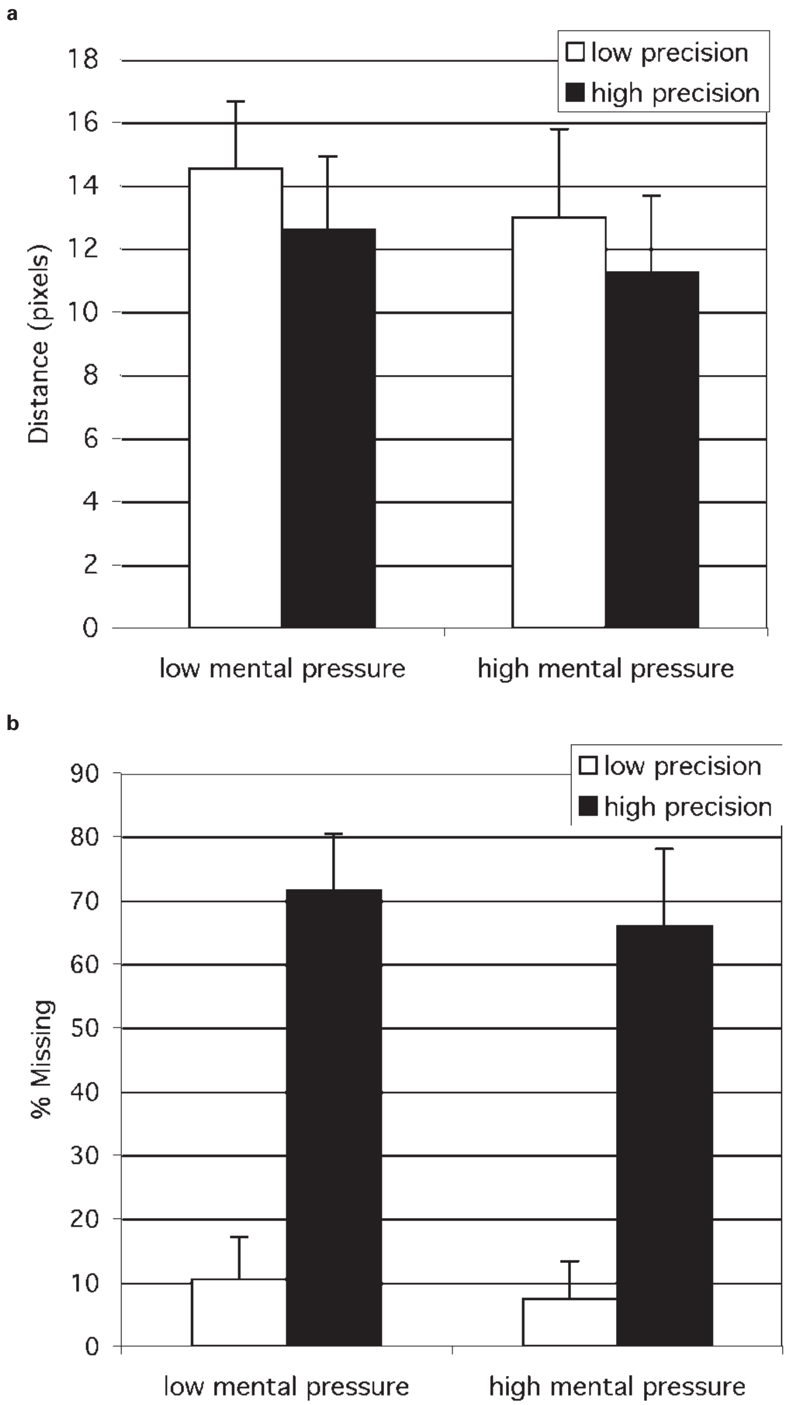


Figure 2. Mean and standard deviation (error bars) of the performance measures for the tracking task at two levels of precision demand and two levels of mental pressure. (a) The mean distance (in pixels) between the cursor and the middle of the target dot (Distance). (b) The percentage of the time the cursor was not positioned on the target dot (% Missing).

Table 1. Effects of precision demands and mental pressure on the performance measures during tracking. Significant effects are indicated with an asterisk *.

	Distance		% Missing	
Tracking	F	*p*	F	*p*
Precision demands	22.39	* 0.001	107.10	* < 0.001
Mental pressure	18.61	* 0.002	6.45	* 0.029
Mental pressure × precision demands	0.03	0.865	4.95	0.050

Table 2. Effects of precision demands and mental pressure on the performance measures during aiming. Significant effects are indicated with an asterisk *.

	Distance		Missed		Time/click	
Aiming	F	*p*	F	*p*	F	*p*
Precision demands	2001.27	* < 0.001	47.18	* < 0.001	525.17	* < 0.001
Mental pressure	0.88	0.373	0.04	0.854	340.72	* < 0.001
Mental pressure × precision demands	0.05	0.829	0.10	0.755	465.22	* < 0.001

There was no significant interaction effect between precision demands and mental pressure on the mean distance between the cursor and the middle of the target dot. An almost significant interaction effect of precision demands and mental pressure was found for the percentage of the time the cursor was not positioned on the target dot.

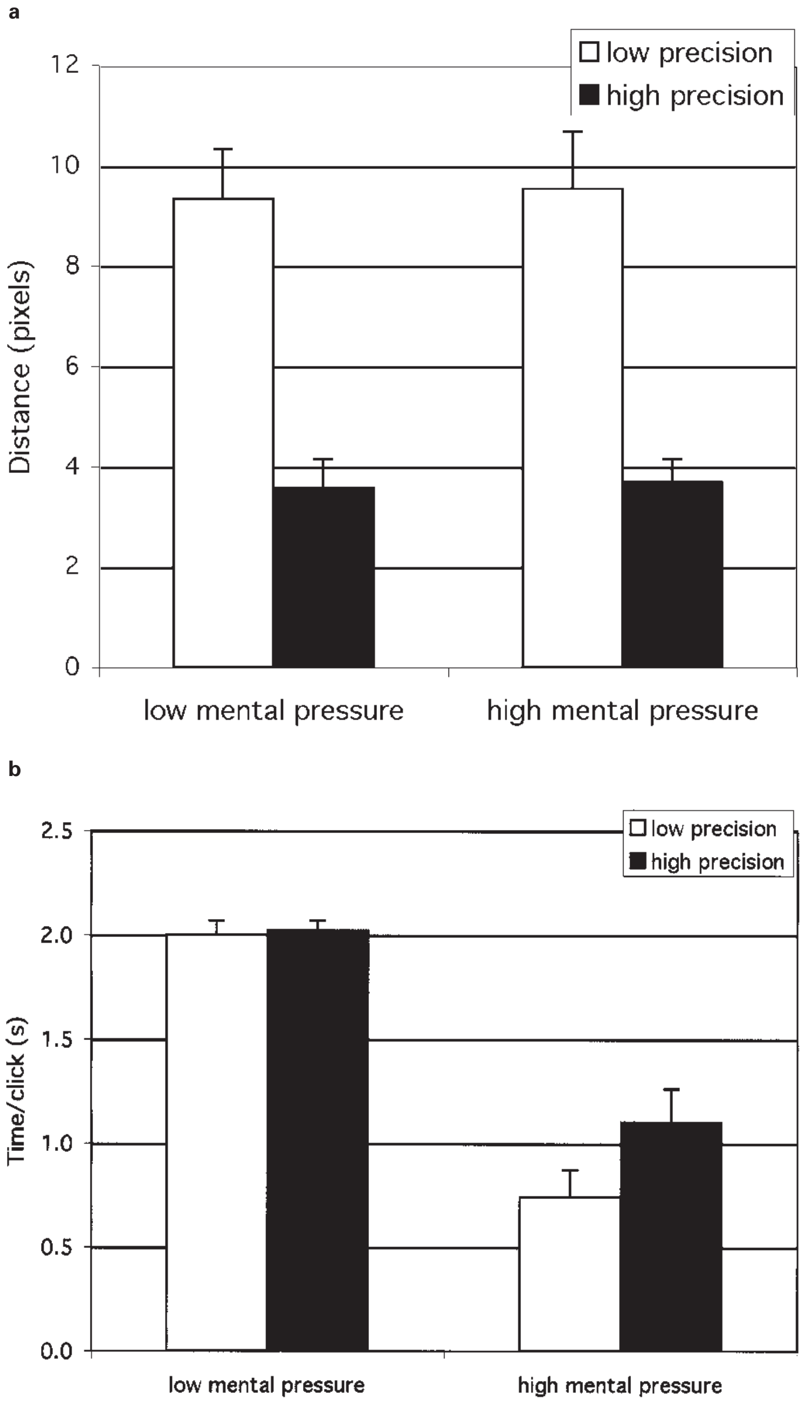
The performance measures for the aiming task are presented in figure 3 and the corresponding statistics in table 2. Precision demands had a marked effect on the three performance measures. High precision demands led to (a) smaller distances between the cursor and the middle of the target dot at the moment of clicking, (b) more missed dots and (c) an increase in time per click, calculated over the first 60 clicks.

Mental pressure only had a significant effect on 'time/click'. High mental pressure led to a decreased 'time/click'.

A significant interaction effect was present between precision demand and mental pressure on the 'time/click', with 'time/click' being dependent on precision in the high mental pressure condition but as expected not in the low mental pressure condition, where it was the intention to click at a constant rate. Post hoc testing showed that under the high mental pressure condition high precision demands led to an increased 'time/click' ($p < 0.001$).

3.2. *Upper extremity load*

Results of upper extremity loading during the tracking tasks are presented in figure 4. The P50 values of the EMG-amplitudes are shown in figure 4a and the grip- force applied to the mouse in figure 4b. The results of the statistical tests for these variables are summarized in table 3. No significant effects of precision were found for the muscle activation or for the grip-force applied to the mouse. Mental pressure had a significant effect on trapezius EMG-amplitude during the tracking task, with high mental pressure leading to 22% higher EMG-amplitude. No significant effects were


a
low precision
high precision
12
10
8
6
4
2
0
Distance (pixels)
low mental pressure
high mental pressure
b
low precision
high precision
2.5
2.0
1.5
1.0
0.5
0.0
Time/click (s)
low mental pressure
high mental pressure

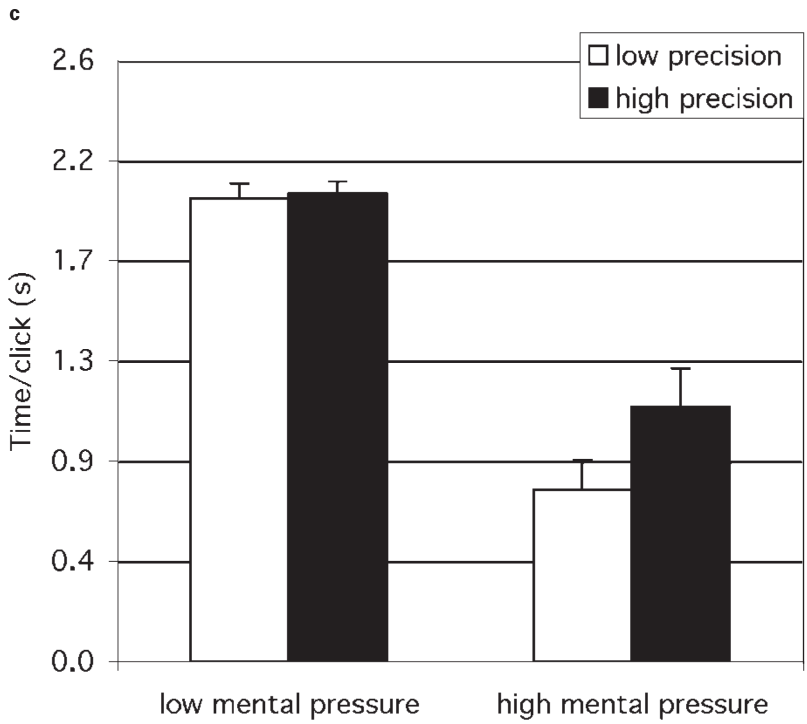
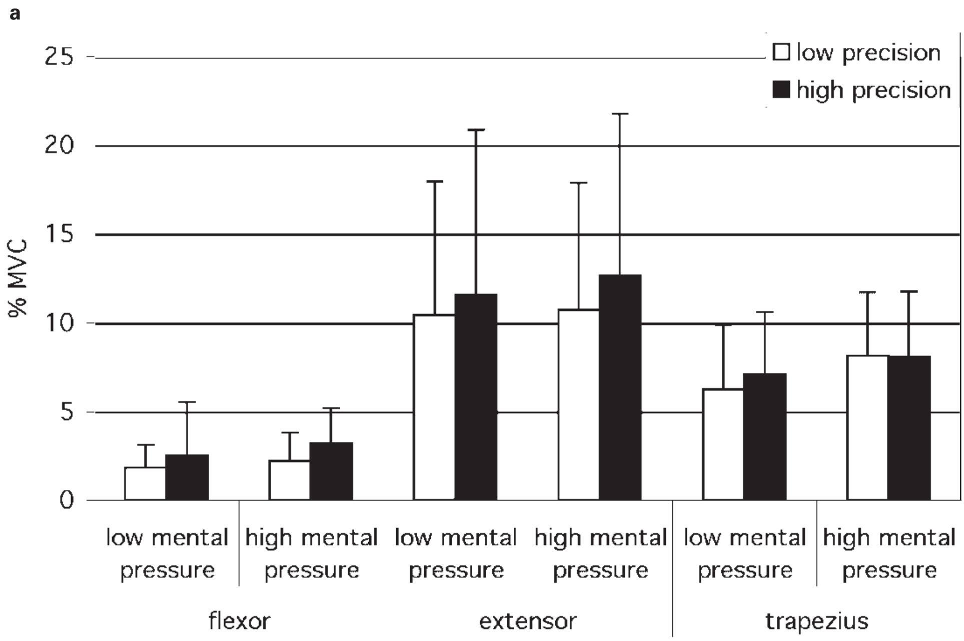


Figure 3. Mean and standard deviation (error bars) of the performance measures for the aiming task at two levels of precision demand and two levels of mental pressure. (a) The mean distance (in pixels) between the cursor and the middle of the target dot at the moment of clicking (Distance). (b) The number of missed dots until 60 correct clicks were made (Missed). (c) The time per click (s), calculated over the first 60 clicks (Time/click).

found on the EMG-amplitudes of the flexor and extensor or on grip-force. No significant interaction effects of mental pressure and precision were found.

Results of upper extremity loading during the aiming task are presented in figure 5. The P50 values of the muscle activation are shown in figure 5a and the results of the grip-force and click-force applied to the mouse in figure 5b. The results of the statistical tests for these variables are summarized in table 4. Precision had a significant effect on the flexor EMG-amplitude with higher precision leading to higher muscle activation. An increase of 21% in flexor EMG-amplitude was found. No significant effects of precision were found for the extensor or trapezius EMG-amplitudes or for the forces applied to the mouse. Mental pressure had a significant effect on the EMG-amplitude of all muscles during the aiming task, with higher mental pressure leading to higher EMG-amplitudes. Increases in EMG-amplitudes for flexor, extensor and trapezius were 142%, 45% and 41% respectively. There was also a significant effect of mental pressure on the grip- and click-forces, with higher mental pressure resulting in higher forces applied to the mouse. Increases in grip-force and click-force were 51% and 40% respectively.

A significant interaction effect of mental pressure and precision was found only in the extensor EMG-amplitude. The interaction shows that effects of precision are more pronounced at low mental pressure.



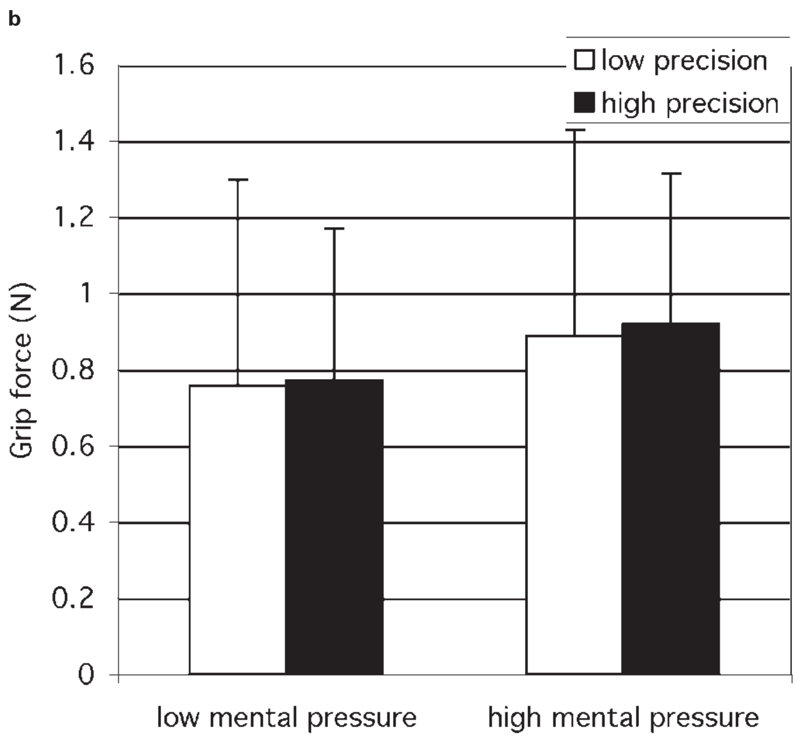


Figure 4. (a) Mean and standard deviation (error bars) of the median (P50) muscle activation level during tracking expressed as percentage MVC of the flexor, extensor and trapezius at two levels of precision demand and two levels of mental pressure. (b) Mean and standard deviation (error bars) of the grip-force (N) during tracking at two levels of precision demand and two levels of mental pressure.

Table 3. Effects of precision demands and mental pressure during tracking on the upper extremity loading measures: EMG-amplitudes of flexor, extensor and trapezius muscles and grip-force on the mouse. Significant effects are indicated with an asterisk *.

	Flexor EMG		Extensor EMG		Trapezius EMG		Grip-force	
Tracking	F	*p*	F	*p*	F	*p*	F	*p*
Precision demands	4.86	0.052	2.05	0.183	0.29	0.601	0.06	0.811
Mental pressure	2.67	0.133	1.79	0.211	7.65	* 0.020	4.86	0.055
Mental pressure × precision demands	0.20	0.667	1.72	0.219	1.06	0.327	0.01	0.931

Table 4. Effects of precision demands and mental pressure during aiming on the upper extremity loading measures: EMG-amplitudes of flexor, extensor and trapezius muscles and grip-force and click-force on the mouse. Significant effects are indicated with an asterisk *.

	Flexor EMG		Extensor EMG		Trapezius EMG		Grip-force		Click-force	
Aiming	F	*p*	F	*p*	F	*p*	F	*p*	F	*p*
Precision demands	8.27	* 0.017	4.67	0.056	0.39	0.546	0.19	0.675	0.13	0.725
Mental pressure	22.59	* 0.001	11.95	* 0.006	6.57	* 0.028	7.39	* 0.024	30.01	* < 0.001
Mental pressure × precision demands	1.12	0.315	7.30	* 0.022	0.85	0.377	0.06	0.809	0.62	0.452

4. Discussion

The goal of this study was to simulate work situations with different levels of mental pressure and precision demand. Both factors of interest were defined in terms of demands to perform at a certain level with respect to accuracy and/or speed. Thus, performance measures could be used to check whether the manipulations were effective in this regard. There were clear effects of precision demands in both mouse tasks on all performance measures. Mental pressure effects were present in both tasks, clearly so in tracking and somewhat less consistently in aiming, where only the 'time/click' was affected. It may therefore be concluded that the levels of the independent variables imposed differed sufficiently to simulate work situations with distinguishable levels of precision and mental pressure. The absence of significant interaction effects of precision and mental pressure for four of the five performance measures indicates that their effects were additive and not multiplicative. The interaction effect found on the 'time/click' in the aiming task was due to the fact that the dots were presented at fixed intervals during the low mental pressure condition, whereas in the high mental pressure condition subjects performed as fast as possible.

Effects of precision on parameters of upper extremity loading were limited and significant only in the aiming task, in spite of the clear effects on performance in both tasks. In other words, the increased effort necessary to achieve the precision demands was reflected in only small changes in muscle activation, which moreover were limited to the forearm region. An explanation for the small increase in muscle activation might be the contribution of intrinsic hand muscles to mouse manipulation. Maier and Hepp-Reymond (1995) performed an experiment on precision grip and concluded that intrinsic hand muscles were responsible for the

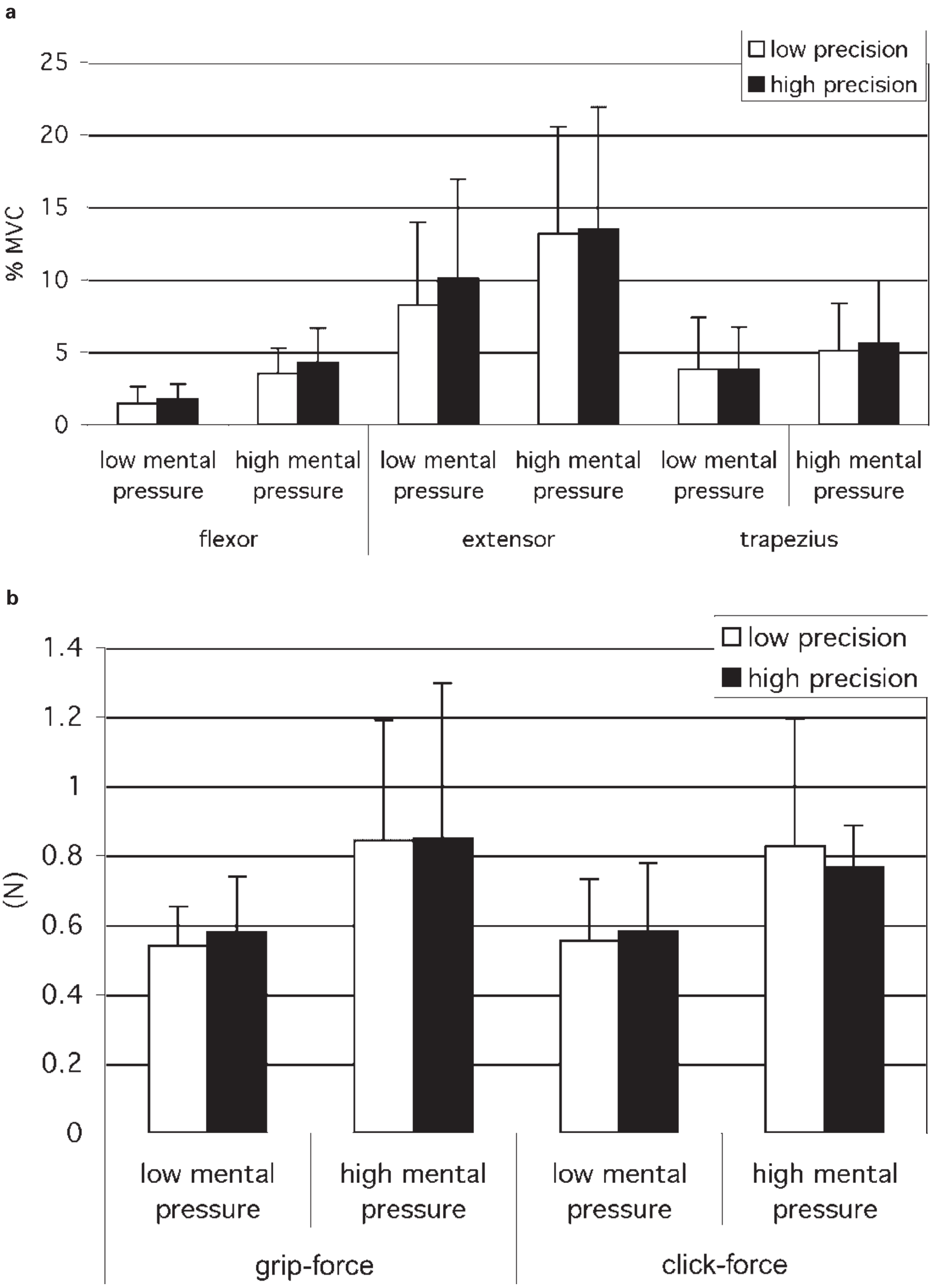


Figure 5. (a) Mean and standard deviation (error bars) of the median (P50) muscle activation level during aiming expressed as percentage MVC of the flexor, extensor and trapezius at two levels of precision demand and two levels of mental pressure. (b) Mean and standard deviation (error bars) of the grip-force (N) and click-force (N) during aiming at two levels of precision demand and two levels of mental pressure.

fine-tuning of the force. The EMG of intrinsic hand muscles was not measured in the present study and thus it is not possible to draw conclusions in this regard.

Effects of precision may also in part have been counterbalanced by a lower productivity. This was illustrated by Birch *et al.* (2000), who investigated simulated computer work with different levels of precision, time pressure, and mental demand. They found that high precision demands and high mental demands did not influence the EMG of upper extremity musculature. However, productivity appeared reduced. It should be noted that in the present study productivity under high precision demand was at least equal to that in the low precision condition, except in the aiming task under high mental pressure. In the latter condition, the productivity increased, indicated by the decreased 'time/click'. In working life, similar effects may occur and this may reduce the effects of precision demands on physical loading.

Two explanations for an increase in muscle activation with increased precision demands can be identified. First, co-contraction may be increased to filter out noise to meet the increased demand. Second, the trajectory choice may differ between precision conditions. Mottet and Bootsma (1999) showed that, with increased precision demands, systematic changes in kinematics occur; most notably movement speed increases in the middle part of the movement and decreases near the target. In other words, higher precision demands lead to higher accelerations in the first part of the movement and higher decelerations in the second part, where the actual precision is required. The effect of precision on the flexor muscle in the aiming tasks may therefore be partly explained by effects of movement speed and acceleration (Laursen *et al.* 1998, Wahlstrom *et al.* 2002).

Previous studies have also found effects of precision demands on EMG activity of both proximal and distal arm muscles (Laursen *et al.* 1998, Sporrong *et al.* 1998, Laursen and Jensen 2000). In the study by Sporrong *et al.* (1998), subjects performed either a positioning task with their arms (holding a stick) or combined this with a tracking task with their hand/wrist (tracking with the point of the stick). Simply holding the stick in position coincided with less trapezius muscle activity than when performing a precise tracking task. This was interpreted as an effect of the high precision demand in the tracking task. However, it is conceivable that reaction moments acting on the shoulder, which would be caused by the accelerations of the hand, were the true cause of the effect. In the study by Laursen *et al.* (Laursen *et al.* 1998, Sporrong *et al.* 1998, Laursen and Jensen 2000) the precision effects may be explained on the basis of differences in movement speed, as in the present aiming task. The study by Laursen and Jensen (Laursen *et al.* 1998, Sporrong *et al.* 1998, Laursen and Jensen 2000), did show significant effects in a tracking task, suggesting that the almost significant effect in the present study was not a chance finding.

Mental pressure had an effect on trapezius activation during the tracking tasks, with higher mental pressure leading to higher muscle activation and the influence of mental pressure on grip-force was close to the border of significance. Mental pressure had an effect on the activation of all muscles during the aiming task, with higher mental pressure leading to higher muscle activation. There was also an effect of mental pressure on the grip- and click-forces in the aiming task, with higher mental pressure resulting in higher forces applied to the mouse. Again the stronger effect in the aiming task may be explained on the basis of differences in movement speed, which was intentionally influenced. The higher EMG amplitudes and higher grip-forces in aiming in the high mental pressure condition may be related to the associated accelerations and decelerations. The increased trapezius muscle activation in tracking cannot be due to the effects of movement speed and acceleration, suggesting that another mechanism must be operating. The neuro-motor noise theory predicts such a direct effect of mental pressure. In addition, an overall increase in arousal (Westgaard 1996, Lundberg 2002) due to the mental effort of performing as well as possible might be operative. This is supported by the increased click-force during aiming, which would not contribute to counteracting neuro-motor noise effects.

Previous studies have also shown effects of work pressure (Waersted 2000, Bansevicius *et al*. 2001, Lundberg 2002). It should be noted that a wide range of stressors, some related to the actual task and others additional to the task, were used in these studies.

The level of muscle activity in the forearm extensor muscles during these intensive mouse tasks was surprisingly high. In addition, trapezius activity appeared high especially in the tracking task. This suggests that mouse tasks pose a health risk, in line with epidemiological findings. The magnitude of this risk would be modified by precision demands and mental pressure, which explains their association with the prevalence of UEMSDs. When comparing the effects of precision and mental pressure, it can be concluded that precision had a much larger effect than mental pressure on performance and mental pressure had a larger effect than precision on upper extremity loading.

The strong effect of precision on the performance measures might have some implications for real computer work, in such a way that making errors might have serious consequences and thereby pose high mental pressure on the worker. Feedback of the performance in the tracking task in the present study (with no other consequence than getting a low end score) was already enough to add mental pressure. It can be argued that, in working conditions where performance is important or even crucial, precision has an indirect effect on upper extremity loading by its strong effect on performance and thereby on mental pressure. In other words, precision demands in real work can be implicit mental stressors.

5. Conclusion

Precision demands and mental pressure in aiming and tracking tasks with a computer mouse were found to coincide with increased muscle activity in some upper extremity muscles and increased force exertion on the computer mouse. Mental pressure caused significant effects on these parameters more often than precision demands. Precision demands and mental pressure were found to have effects on performance, with precision effects being significant for all performance measures studied and mental pressure effects for some of them. The results of this study suggest that precision demands and mental pressure increase upper extremity load, with mental pressure effects being larger than precision effects.

Acknowledgements

The data of the present study were collected in the GEMINI-project funded by Dräger, Business Unit HomeCare. We would like to acknowledge the contributions of the GEMINI-project group: H. A. Cramer, K. M. van der Hel, M. G. H. Meijerink and B. D. Netten. P. J. Beek and M. Douwes are acknowledged for reviewing an early version of the manuscript.

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